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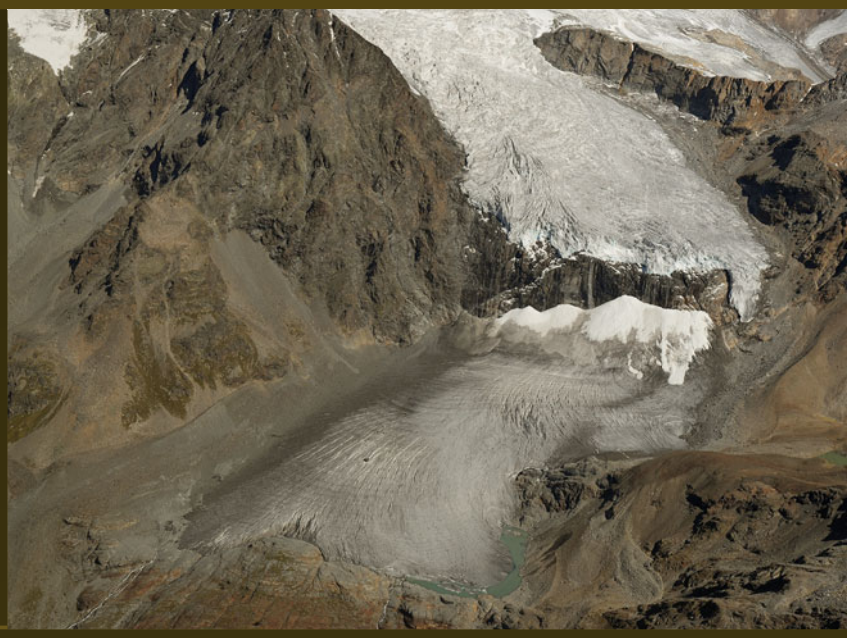

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Cover Illustration: The Fellaria Glacier (Bernina Massif, Central Italian Alps). The lowest part of the Fellaria glacier tongue, more than 1 km long, was cut in 2006 from the upper glacier mass in correspondence to a rock cliff. Glaciers are among the best indicators of climate change, thanks also to their clear visibility to the public. *Photo Courtesy*: Giovanni Kappenberger.

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Role of Climate and Land Use Variations on the Occurrence of Damaging Hydrogeological Events in Apulia (Southern Italy)

24

Teresa Lonigro and Maurizio Polemio

Abstract

The aim of this work is to present a methodology, based on the use of correlation, cross-correlation and trend analysis, which analyses monthly climatic data (rainfall, wet days, rainfall intensity, and temperature) from 1877 to 2008, in order to characterise the climate variations, particularly in terms of rainfall, and the effects on the occurrence trend of Damaging Hydrogeological Events (DHEs), floods and landslides. The proposed methodology consists of four phases. The first two phases concern the data collection and the creation of the climate and DHE databases, the third phase of work involves the analysis of data previously collected and the last part, not yet finished, is relative to the study of land use variations. This methodology was applied to a southern Italian region (Apulia) frequently hit by flood and landslide events. Despite the decreasing trend of rainfall and rainfall intensity and the increasing trend of temperatures and wet days, there is an increasing trend of DHE occurrence, which might related to the negative effect of anthropogenic activities in landslide-prone areas. The preliminary analysis on land use variations confirmed the increase of urban areas in the Apulia region from the 1959 to the 2006.

Keywords

Climate change • Land use • Landslides • Floods • Apulia

24.1 Introduction

Recent international research has underlined the evidence of climate change throughout the world, which is evident in the gradual, but constant, rise of temperatures and in the variation in the distribution of rainfall, which are concentrated in certain periods of time, often assuming exceptional intensities (EEA 2008). Among the consequences of these climate conditions there is the increase in the frequency and magnitude of natural disasters, such as droughts, windstorms, heat waves, landslides, floods and secondary floods (i.e. rapid accumulation or pounding of surface water with very low flow velocity). The Damaging Hydrogeological Events (DHEs) can be defined as the occurrence of one or more simultaneous aforementioned phenomena causing damages (Petrucci and Polemio 2002). They represent a serious problem, especially in DHE-prone areas with growing urbanisation. In these areas the increasing frequency of extreme hydrological events could be related to climate variations and/or urban development. The historical analysis of DHEs can support decision making and land-use planning, ultimately reducing natural risks.

The research was realized at CNR-IRPI in the context of PhD school in "Plant sciences and environmental technologies", specializing in "Management and engineering of biosystems agroforestry" of the University of Bari "A. Moro".

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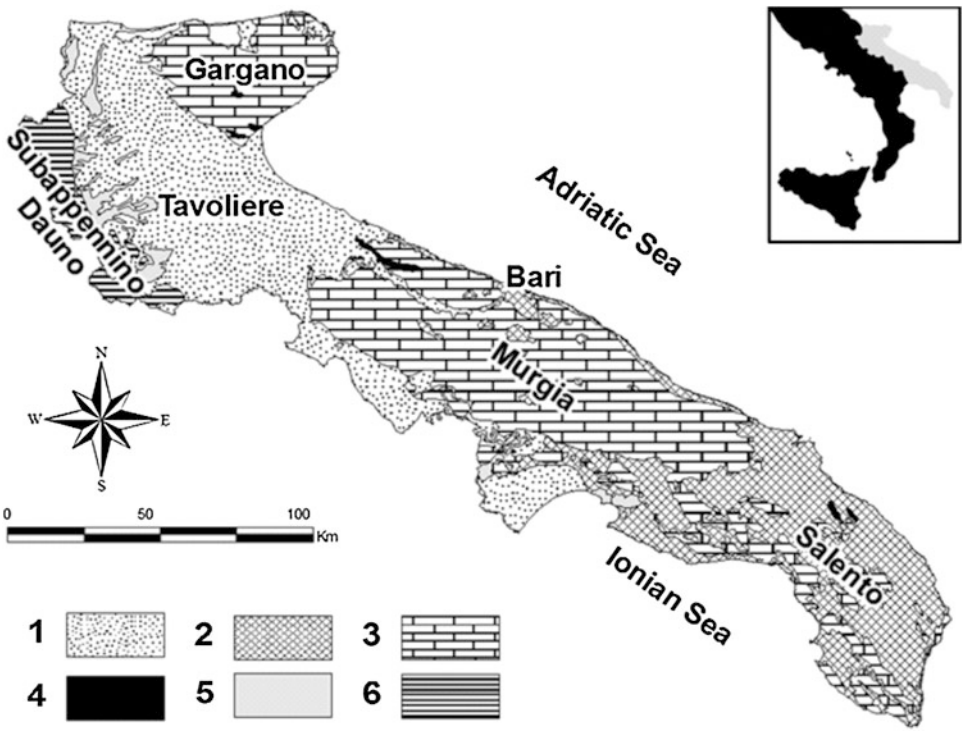

Fig. 24.1 Apulian geological-technical map. *1* Sandy clay, clayey sand, sand and gravel; *2* Sand, silt, calcareous sandstone, limestone and dolomite; *3* Limestone and dolomite; *4* Calcareous sandstone and sandstone; *5* Marly clay; *6* Flysch

The paper proposes a methodology, based on both historical and time series approaches, used for describing the influence of climatic variability on the number of phenomena observed. The historical approach is finalised to collect phenomenon historical data, very important for the comprehension of the evolution of a study area, especially in DHE-prone areas (Petrucci and Polemio 2002). Phenomenon historical data is useful for expanding the historical period of investigation in order to assess the occurrence trend of DHEs. The time series approach includes the collection and the statistical analysis of climatic data (monthly rainfall, wet days, rainfall intensity, and temperature), which are also used as a proxy data for floods and landslides. The climatic data are useful to characterise the climate variations and trends and to roughly assess the effects of these trends on river discharge and on the triggering of landslides. The time series approach is completed by tools to analyse simultaneously all data types. The study of land use variations is important to understand how the modifications occurred in the territory, especially in terms of vulnerability, could influence the occurrence of DHEs (Palmieri et al. 2011). The methodology can be applied simultaneously to floods and landslides and was tested considering a selected Italian region (Apulia, southern Italy), particularly affected by climate changes, enduring significant effects in terms of the decreasing trends of water availability (Polemio and Casarano 2004; Polemio et al. 2011).

24.2 The Apulian Case Study

The Apulia region can be divided into five physiographic units: Gargano, Tavoliere, Subappennino Dauno, Murgia, and Salento (Fig. 24.1). From east to west, it is possible to recognise three different geological domains related to Apennine orogenic phase, the foreland, the foredeep and the chain. The foreland is made primarily of the carbonate platform sediments deposited during the Upper Jurassic—Cretaceous (Cotecchia et al. 2005); it is composed of micritic limestones, with a fairly high fossil content. Moving westward, there are Plio—Pleistocene units in transgression on the carbonate platform units; the entire cycle of sedimentation includes limestones, clays, sands and conglomerates. In the Subappennino Dauno, there are units belonging to the Apennine chain; they consist primarily of carbonate silicoclastic and marine deposits, which settled in different pre-orogenic sedimentary basins. The tectonic forces then stacked these sediments, which, at present, are chaotic and strongly tectonised. As a consequence, these sediments present poor geotechnical properties, characterising the Subappennino Dauno as the landslide-prone Apulian physiographic unit.

The main source of records of DHEs for Apulia was the AVI database (CNR-GNDCI 1999), which was useful for the period 1918–1996. This source was integrated up to 2006 by consulting newspapers, publications and technical reports kept by the authors' Institute. In Apulia, 251

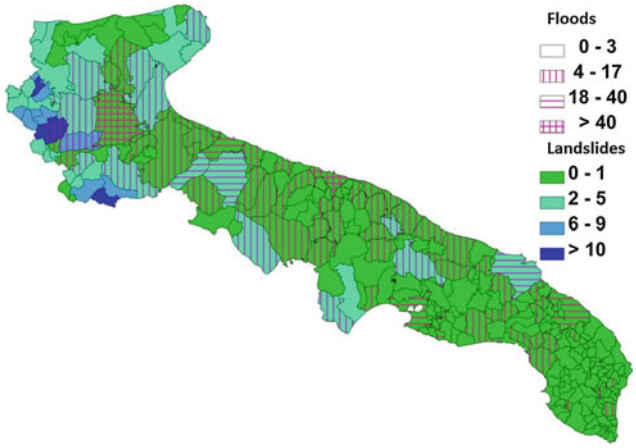

Fig. 24.2 Recurrence of DHEs (1918–2006)

landslides (the first recorded landslide was in 1928) and 935 floods were documented. Landslide and floods monthly time series were defined both for each municipality and for the entire region. The whole dataset was implemented in a GIS environment (Fig. 24.2).

The spatial distribution of floods indicated that floods were not rare where karstic outcropping features are observed (Polemio 2010). The two highest occurrence classes (>18 floods) were typical of the municipalities of Tavoliere, Salento, and Murgia, where the main regional towns are located. The regional distribution of landslides underlined the high concentration of these events in the area of the Subappennino Dauno, where the two highest occurrence classes were observed. This could be justified considering the geological, morphological, and geotechnical features for which Subappennino Dauno could be a landslide-prone area.

The climate database was realised by collecting monthly data on rainfall R, temperature T and wet days WD (days in which precipitation is equal to or greater than 1 mm) from the Annali Idrologici (annual publication of the national hydrological service), published from 1919 to 1996. This database has been integrated with historical data from 1877. The most recent data (until 2008) were provided by the Centre of Functional Service of Civil Protection of Regione Puglia. For each month and rain gauge, the monthly-mean rainfall intensity of wet days (following rainfall intensity or I) was calculated as the ratio between the monthly rainfall R and the monthly number of wet days WD. The following text always refers to the hydrological year, which runs from September to August. Sixty rainfall gauges/time series were selected, 47 of which were also thermometric. The selection was optimised by maximising time series length, minimising time series gaps and pursuing a sufficient gauge density.

To simplify the complexities of the spatial-temporal analysis of changes in the climate, the damaging landslide and flood occurrences and the relationship between these variables, monthly (RI, WDI, II, TI, LI, and FI) and annual indices (Ry, WDy, Iy, Ty, Ly, and Fy) were defined by reducing the discussion to a discussion of time series (see Polemio and Petrucci 2010 for more details).

Table 24. 1 Trend and correlation coefficient between annual indices

	Fy	Ly	Ry	WDy	Iy	Ty	Trend
Fy	1.00						I
Ly	0.12	1.00					I
Ry	0.36	0.14	1.00				D
WDy	0.36	0.18	0.80	1.00			I
Iy	0.17	−0.02	0.56	0.12	1.00		D
Ty	0.04	0.26	−0.32	−0.42	−0.02	1.00	I

Fy, *Ly*, *Ry*, *WDy*, *Iy*, *Ty* are respectively flood, landslide, rainfall, wet days, rainfall intensity, and temperature indices; *I* increasing, *D* decreasing

24.3 Results and Conclusions

The correlation analysis between annual indices underlined a positive and direct correlation between landslides from a side and rainfall, wet days, and temperature from the other side, while an indirect and very low correlation was noticed between landslides and rainfall intensity. The correlation between the flood indices and annual climate indices was always direct, with higher values compared to those obtained in the case of landslides (Table 24.1). The trend analysis showed a decreasing trend of rainfall and rainfall intensity and an increasing trend of wet days and temperatures, in agreement with what is known for all of southern Italy (EEA 2008; Polemio and Casarano 2004).

The climate trend, overall, does not show favourable conditions for the increase of the annual DHEs number. Nevertheless, the trend of the annual number of damaging landslides and floods is positive or increasing (Fig. 24.3).

If there is not an evident relationship between climate variability and the increasing trend in the occurrence of DHEs, the role of anthropogenic modifications and the mismanagement of risk-prone areas should be considered to justify the increasing occurrences of floods and landslides.

To reduce the uncertainty in the results described above, the research is being expanded with two approaches: the improvement of DHEs database and the study of land use modifications.

For the improvement of DHEs dataset further data were collected searching in the archives of regional libraries. About 700 useful news from 17 different local newspapers were found from 1876 to 1951. From a critical analysis of the 700 news collected since 1876–1952 only 437 were useful for the implementation of the Apulia DHEs database. The screening of the selected sources is still in progress and the expansion of the database is not concluded yet.

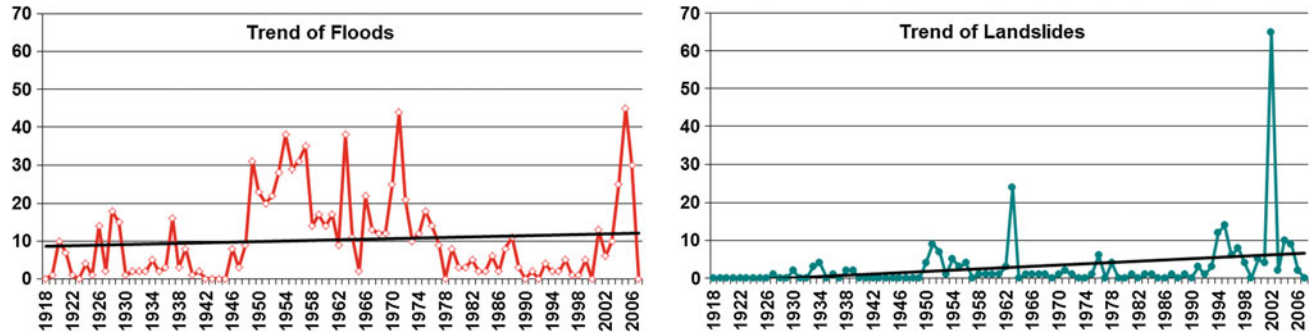

Fig. 24.3 Time series of annual flood and landslide number and trend

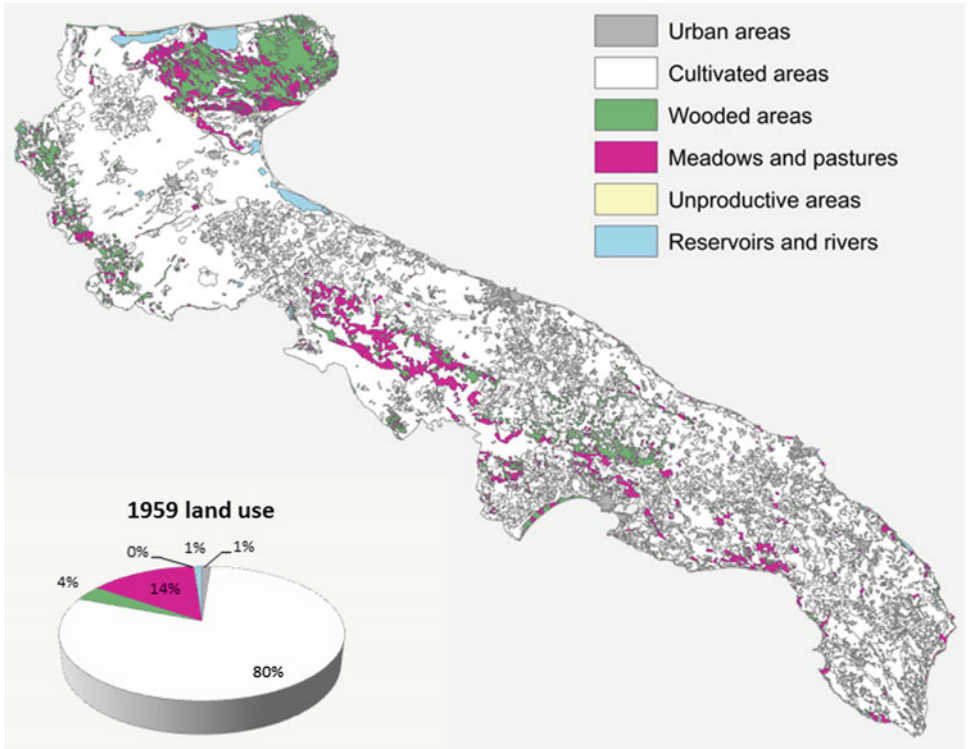

Fig. 24.4 2006 Apulian land use map and land use diagram of 1959

For the comprehension of land use modifications the available data were represented by the "Corine Land Cover" programme for the years 2006, 1999 and 1990 and the "Land use Map" edited by CNR-TCI of the 1959, which was acquired in digital format, loaded in a GIS environment, georeferenced and digitalized.

It was necessary to create a legend that was useful both for Corine Land Cover levels and for the Land use Map. A new legend was created; it was composed by six fields, representing the principal uses of land (Fig. 24.4). A preliminary analysis showed, starting from 1959 to 2006, a significant increase in urban areas (from 231 to 898 km^2), cultivated areas (from 15,392 to 15,576 km^2), and wooded areas (from 716 to 1,429 km^2), and a decrease in the meadows and pastures (from 2,772 to 1,168 km^2).

Notwithstanding the increase of wooded areas, the increasing vulnerability due to the expansion of urban areas and anthropogenic activities could justify the increasing occurrence of the DHEs on the Apulian territory. This phase of the study is not yet completed and the above considerations have to be validated with higher accuracy.

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